CSVTU International Journal of Biotechnology, Bioinformatics and Biomedical
Vol. 3(2), 01–16, 2018
ISSN: 2455-5762

Research Article

External Nutrient Load and Determination of the Trophic Status of Lake Ziway

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HIGHLIGHTS

- This study aims to evaluate external nutrient loads and determine trophic status of Lake Ziway
- Katar and Meki Rivers are the major sources of the external nutrient load of the lake ecosystem
- Total phosphorus, Chlorophyll-*a* and secchi depth are important trophic state variables
- Currently Lake Ziway is under eutrophic condition

G R A P H I C A L A B S T R A C T

Abstract

Lake Ziway is shallow freshwater located in Northern part of Ethiopian Rift Valley. Expansions of the flower industry, fisheries, intensive agricultural activities, fast population growth lead to deterioration of water quality and depletion of aquatic biota. The objectives of the present study are to evaluate the spatial and temporal variations in the external nutrient load and determine the trophic status of Lake Ziway in 2014 and 2015. The nutrients and Chlorophyll-*a* were measured according to the standard procedures outlined in APHA, 1999. From the result Ketar and Meki Rivers catchment showed the major sources of external nutrient loads to the lake ecosystem. The mean external soluble reactive phosphorus (SRP), total phosphorus (TP), total inorganic nitrogen (TIN) and total nitrogen (TN) loads to Lake Ziway were 230, 2772, 4925 and 24016 kg day^{-1}, respectively. A general trend which was expected that the nutrient loads would be much higher in rainy season than in dry season. The mean concentrations of trophic state variables for TN, TP and Chl*a* were 6700, 212 and 42 μg L^{-1}, respectively. The mean values of TSI-TP, TSI-Chl-*a*, TSI-TN and TSI-SD were 79, 66, 81 and 83, respectively and the overall evaluation of Carlson Trophic State Index (CTSI) of Lake Ziway was 77. Therefore, the lake is under eutrophic condition. The mean values of TN: TP ratio was 48 which were very high. The trophic state index determined with chlorophyll-*a* showed lower value than those determined with all trophic state indices values of TN, TP, and SD which indicated that non-algal turbidity affected light attenuation for algal growth. This suggested that phosphorus was the limiting nutrient in Lake Ziway. Due to its importance as being the lake is an intensive agricultural site, management solutions must be urgently developed in order to avoid the destruction of the lake.

Key words: Lake Ziway, external nutrient load, eutrophication, trophic status, chlorophyll-*a*

1. INTRODUCTION

Nowadays, as the world population grows, the need to produce more food increases on limited agricultural space with intensified practices. This led to further increase in nutrient inputs and intensification of agriculture. In countries like Ethiopia where the plant-soil-water relations are not monitored, excess and untimely application of agrochemicals into farmlands lead to anthropogenic eutrophication problems in freshwater that are at the receiving ends of the hydrologic system [1-3].

The highly turbid water in Africa in particular to Ethiopian lakes, which are also highly vulnerable to degradation of their watershed with human activities. Thus, information from developing countries on this approach could provide insight regarding the global trends of nutrient load in associated with lake trophic status of the aquatic environment. It is known that if nutrient load is excessive, the growth of phytoplankton is favored and this has significant negative implications for the overall water quality and biodiversity of the lake: the water becomes turbid, toxic algae may develop, submerged macrophytes disappear, fish stock changes toward less desirable species and top-down control by zooplankton on phytoplankton disappears [4-6].

Lake Ziway is primarily loaded by two rivers, namely, the Meki River that drains the western Guraghe Mountains contributes 278 MCM and the Ketar River, which drains in the eastern Arsi Mountains, contributes 302 MCM water to the lake. As a consequence, these two rivers carry heavy sediment and nutrient loads to the lake. In view of the importance of this kind of study, the present work has estimated the external nutrient loads discharged exclusively via the Ketar and Meki rivers into Lake Ziway over a period of two years. Moreover, there is also a very limited work done on the trophic status associated with nutrient load of Lake Ziway. Therefore, the main objectives of the present study are to evaluate the spatial and temporal variations in the external nutrient load and determine the trophic status of Lake Ziway.

2. Materials and Methods

2.1 Description of the Study Area

Lake Ziway is a shallow freshwater lake found in the most northern section of the Ethiopian Rift Valley and is located at $08^{0}01'$N and $38^{0}47'$E (Fig. 1). It is located about 163 km south of Addis Ababa. The woredas holding the lake's shoreline are Adami Tullu and Jido Kombolcha, Dugda Bora, and Ziway Dugda [7-9].

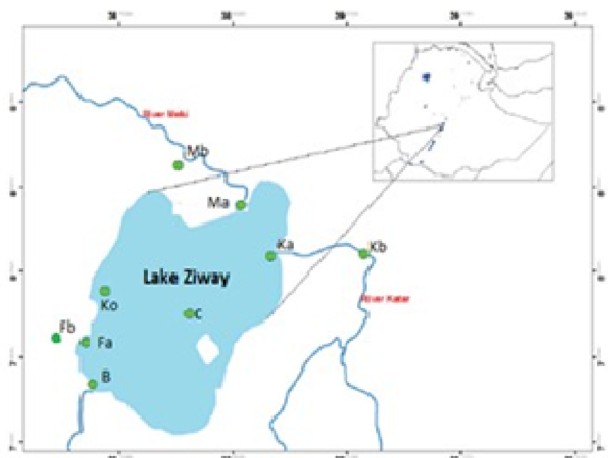

Figure 1 Lake Ziway sampling sites in the lake and its feeder rivers in Ethiopia

Table 1 Geographic coordinates of the sample points

Sampling Site Description	Abr.	North	East	Elevation
Floriculture effluent	Fb	$07^{0}54.715'$	$038^{0}44.020'$	1642
Floriculture after mixing	Fa	$07^{0}54.79'$	$038^{0}44.111'$	1639
Bulbula River mouth	B	$07^{0}53.943'$	$038^{0}44.134'$	1641
Ketar River mouth	Ka	$07^{0}55.398'$	$038^{0}52.086'$	1640
Ketar River at Abura Town	Kb	$08^{0}02.019'$	$038^{0}49.340'$	1646
Meki River at Meki Town	Mb	$08^{0}03.019'$	$039^{0}01.144'$	1673
Meki River mouth	Ma	$08^{0}03.379'$	$038^{0}56.459'$	1633
Korekonch	Ko	$07^{0}55.494'$	$038^{0}43.697'$	1637
Central station	C	$07^{0}55.\ 49'$	$038^{0}52.934$	1635

Lake Ziway is well known for its aquatic bird life and other aquatic animals such as the different fish species, various species of phytoplankton, zooplankton and other micro flora, there are also terrestrial plants and animals found around the lake constituting its fauna and flora as per IBC, [10]. The lake's catchment has an area of 7025 square kilometers. The Lake Ziway region is characterized with a semi-arid to sub-humid type of climate and has mean annual precipitation varying between 346 mm and 1042 mm and mean annual temperature between 11.44 to 28 °C. Table 1.1 showed the selected sampling sites of the lake and major inflows and outflow Rivers of lake Ziway.

2.2 Chemicals and reagents

Analytical reagent grades sodium hydroxide, concentrated hydrochloric acid, concentrated sulfuric acid, concentrated phosphoric acid, ammonium persulfate, potassium persulfate, Phenol, sodium nitroprusside, sulfanilamide, N-(1-naphthyl)-ethylenediamine dihydrochloride, sodium salicylate, potassium sodium tartarate, boric acid, potassium antimony tartrate, ammonium molybdate, ascorbic acid, ethanol, phenolphthalein, hypochlorite, acetone, were obtained from Addis Ababa University. All chemical and reagents are products of Sigma-Aldrich, Germany.

2.3 Apparatus and equipment

High speed centrifuge (Hermle Labortechnik; USA), vacuum pump evaporator (Heidoph, 517/6100/0, Germany); UV-Visible Spectrophotometer (Jenway 6405, UK); Ultrasonicator (Decon, Fs100b, Germany); Shaker Bath (Fifty, GCA, 60647, USA); Kjeldahl apparatus (Gallenhamp, USA); Oven dry (Binder, Germany); Turbidimeter (T-100, Singapore); portable multi meter (HACH MM150, China) were used in the experiments.

2.4 Water Sample collection

Water samples were collected with a Van Dorn bottle sampler from different depths of the entire water column with 1 m intervals in the years 2014 and 2015. It was then mixed in equal proportions to produces composite samples at monthly intervals from nine selected sampling sites of the lake and inflow and outflow rivers. The collected water samples were kept in 1 L polyethylene plastic bottles. All water samples were stored in insulated cooler containing ice and taken on the same day to laboratory and stored at 4 ºC before analysis.

2.5 Standard analytical methodologies for nutrient analysis

Over the two years sampling periods (2014 and 2015), the chemical analyses of nutrients and chlorophyll-*a* were determined for all monthly samples following the standard procedures outlined in American Public Health Association as given in APHA, [11]. The samples to be used for the analyses of all nutrients except, total nitrogen (TN) and total phosphorus (TP) were filtered through Glass Fiber filters (GF/F) 0.47 µm in diameter.

Soluble reactive phosphorus (**SRP**) was measured colorimetrically using ascorbic acid method following the standard procedures [11]. The filtered sample was mixed with ammonium molybdate that forms molybdo-phosphoric acid with any phosphate present in the water sample. The acid is then reduced by ascorbic acid to a blue complex known as molybdenum blue. The color intensity, which is proportional to the concentration of phosphate in the water sample, was then measured by a Jenway 6405 UV Visible spectrophotometer at a wave length of 880 nm.

Total phosphorus (TP) was analyzed by persulfate digestion followed by the ascorbic acid method. In the persulfate digestion process, the polyphosphates are converted to the orthophosphate form by a sulphuric acid digestion and organic phosphorus is converted to orthophosphate by a persulfate digestion. The resulting orthophosphate ion (PO_4^{3-})

from unfiltered sample was analyzed by ascorbic acid method as mentioned above (Soluble reactive phosphorus analysis).

Ammonia-Nitrogen (NH_3-N) was determined by Phenate method using spectrophotometer at wave length of 640 nm where an intensely blue compound, indophenol, is formed by the reaction of ammonia, hypochlorite, and phenol catalyzed by sodium nitroprusside. The blue indophenol is proportional to the ammonia concentration in the sample (APHA, 1999).

Nitrite-Nitrogen (NO_2-N) was determined by colorimetric method (APHA, 1999) through the formation of a reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulfanilamide with *N*-(1-naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride). The spectrophotometer measurements was done at a wave length of 543 nm.

Nitrate-Nitrogen (NO_3-N) was determined by salicylate colorimetric method [12]. The analysis is based on the reaction of the nitrate with sodium salicylate in a sulphuric acid medium, which is formed yellow colour salt of nitrosalicylic acid. The colour intensity which is proportional to the nitrate concentration and the nitrates concentrations as nitrogen was measured using Jenway 6405 UV Visible spectrophotometer at a wave length of 410 nm.

Total nitrogen (TN) in water samples was analyzed using Kjeldahl method as stated in APHA, 1999, which involves two-step process. First, the sample was digested with a sulphuric acid to convert organic nitrogen compounds to NH_4^+. Secondly, the converted NH_4^+ was converted to NH_3 in an alkali distillation process. The liberated NH_3 in this process was then quantified to determine the total nitrogen in the original digest.

2.6 Biomass as chlorophyll-*a* of phytoplankton analysis

Chlorophyll-*a* was determined with acetone extraction method (APHA, 1999) [11] where different volume of a water sample was filtered with an electric filtration unit through prewashed Whatman GF/F 0.47 µm diameter filters. Extraction was carried for overnight using 5 mL of 90% acetone. Chlorophyll-*a* absorption was then determined using a Jenway 6405 UV/Visible Spectrophotometer by measuring the absorbance at 665 and 750 nm wavelength after zeroing using acetone. The formulae by Talling and Driver [13] were used to calculate the chlorophyll-*a* concentration.

Secchi depth was measured with a standard secchi disk of 20 cm diameter.

2.7 External nutrient load model

The major external nutrient sources of Lake Ziway are the Ketar and Meki Rivers. The annual nutrient loads to the lake were estimated by multiplying the monthly concentrations of significant forms of nutrients in the rivers by the monthly average inflows of the two rivers. Therefore, the external nutrient load of the lake can be computed using the method of Huai-en *et al.* [14] as follows:

$$\mathrm{L} = K\left(\sum_{i=1}^{n}(\mathrm{Ci} * \mathrm{Qi})\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

Where: L = nutrient load (ton year^{-1}); K = a factor to convert from time period of record to annual value; n = number of samples; Q_i = discharge (m^3 s^{-1}); C_i = concentration (ton m^{-3}).

The records of monthly discharges of Meki, Ketar and Bulbula Rivers were obtained from Ministry of Water, Irrigation and Energy, Ethiopia.

2.8 Determination of the trophic state and trophic state indices

The trophic status of Lake Ziway was determined using the Carlson [15] and Kretzer and Brezonik [16]. Equations described by Carlson [15] (1977) (Equations 1.2 to 1. 4) and Kretzer and Brezonik [16] (Equation. 1.5):

TSI-TP = $14.42 \ln(TP) + 4.15$ …………………..…1.2

$$TSI - SD = 60 - 14.41\ln\,(SD) \qquad 1.3$$

$$TSI - Chla = 9.81\ln\,(Chla) + 30.6 \qquad 1.4$$

$$TSI - TN = 54.54 + 14.43\ln\,(TN) \qquad 1.5$$

Where: TSI-TP = trophic state index referenced to total phosphorus, (TP) = total phosphorus (μg L^{-1}); TSI-SD = trophic state index referenced to Secchi depth, SD = Secchi depth in meters (m); TSI-Chla = trophic state index referenced to chlorophyll-*a*, Chla = chlorophyll-*a* (μg L^{-1}); TSI-TN = trophic state index reference to total nitrogen, (TN) = total nitrogen (mg L^{-1}), while In = natural logarithm.

2.9 Data analysis

Analysis of variance (ANOVA) was conducted to test the differences between, and within, sampling sites at 95 % confidence interval using SPSS (version 20) software. The differences between sites were examined to determine the spatial variation while the differences within seasons addressed the temporal variation.

3. RESULTS AND DISCUSSION

3.1 Seasonal external nutrient concentrations and loads to the lake ecosystem

The concentration of SRP ranged from 0.0 to 0.23 mg L^{-1} and 0.05 to 0.12 mg L^{-1} with mean concentrations of 0.07 mg L^{-1} and 0.08 mg L^{-1} in the dry and wet seasons respectively (Table 2 and 3). No Statistically significant differences among the sampling stations were found (Kruskal-Wallis test, $p < 0.05$). The mean SRP concentrations in Ketar and Meki Rivers found in this study were 0.065 and 0.09 mg L^{-1}, respectively which is higher than 0.029 and 0.024 mg L^{-1} reported by Tamire and Mengistu [17], respectively. The increasing trend in SRP is probably because of nutrient enrichment of the lake from anthropogenic sources in the catchment area.

TP concentration ranged between 0 to 0.76 mg L^{-1} and 0.16 to 1.52 mg L^{-1} in the dry and wet seasons, respectively (Tables 2 and 3). ANOVA (Kruskal-Wallis test) applied for statistical analyses showed that TP values between sampling sites were significantly different ($P < 0.05$).

The concentrations of total inorganic nitrogen (TIN) ranged between 0.0 to 1.86 mg L^{-1} and 0.76 to 3.09 mg L^{-1} with mean concentrations of 0.84 mg L^{-1} and 1.79 mg L^{-1} during the dry and wet seasons respectively (Tables 2 and 3). The highest concentration of TIN was 1.86 mg L^{-1} and 3.09 mg L^{-1} during dry and wet seasons, respectively. The mean TIN concentration was higher during the wet season as compared to dry season. The increased values for TIN might probably due to fertilizer runoff, and domestic sewage from the lake watershed.

Table 2 Seasonal variations of nutrient concentrations (mg L^{-1}) in Ketar and Meki Rivers in dry season in 2014 and 2015

Sites	Month	TP	SRP	TIN	TN
Kb	Nov.	0.18	0.04	0.82	5.45
	Dec.	0.21	0.05	0.81	4.00
	Jan	0.24	0.07	1.10	5.43
	Feb.	0.76	0.04	0.96	6.96
	Mar.	0.35	0.09	0.91	5.12
	April	0.25	0.06	1.32	6.12
Mb	Nov.	0.20	0.06	0.52	5.60
	Dec.	0.18	0.08	0.21	9.60
	Jan.	0.19	0.05	0.83	8.40
	Feb.	0.18	0.23	1.86	3.52
	Mar.	0.21	0.10	0.60	2.23
	April	0.00	0.00	0.00	0.00
Total mean		0.25	0.07	0.84	5.23

The mean TIN concentrations in Ketar and Meki Rivers found in this study was 1.43 and 1.20 mg L^{-1} respectively which were higher than 0.098 and 0.314 mg L^{-1} reported by Tamire and Mengistu [17], respectively. The increased TIN concentrations in this study might be associated with anthropogenic impacts around the lake watershed and climate changes. The increase in rainfall might cause flushing of upland soils. In the dry season increased temperature, reduced inflow and increased residence time give enhanced denitrification and lower TIN concentrations. However, further downstream, where the input from agriculture and point sources is larger, the effect of reduced dilution in the dry season becomes more important than that of increased denitrification, giving increased concentrations also in the dry season [18]. TN concentrations in the two rivers ranged from 0 to 9.6 mg L^{-1} and 3.5 to 10 mg L^{-1} during the dry and wet seasons, respectively (Tables 2 and 3).

Table 3 Seasonal variations of nutrients concentrations (mg L-1) in Ketar and Meki Rivers in wet season in 2014 and 2015

Sites	Months	TP	SRP	TIN	TN
Kb	May	0.16	0.10	0.97	3.50
	Jun.	0.22	0.05	1.47	7.50
	Jul.	0.78	0.08	3.09	7.00
	Aug.	1.18	0.06	1.95	9.80
Mb	May	0.96	0.11	2.40	5.00
	Jun.	0.35	0.06	1.81	6.50
	Jul.	1.07	0.07	1.83	8.56
	Aug.	1.52	0.12	0.76	10.00
total mean		0.76	0.08	1.79	7.20

TN concentrations in the two rivers ranged from 0 to 9.6 mg L^{-1} and 3.5 to 10 mg L^{-1} during the dry and wet seasons, respectively (Tables 2 and 3). ANOVA (Kruskal-Wallis) applied for statistical analyses showed that TN values between sampling sites were not significantly different ($P > 0.05$). Shah *et al.*, [19] suggests that TP concentration in excess of 0.01 mg L^{-1} and TN concentration above 0.3 mg L^{-1} are adequate to cause nuisance algal blooms. Since eutrophication is due to nutrient input, any activity in the watershed of a lake that increases nutrient input causes eutrophication [19]. Currently, the water residence of the lake is 6.67 years which is very suitable to phytoplankton growth in Lake Ziway.

The results of Table 4 showed the external nutrient loads from the two rivers (Meki and Ketar Rivers) entering to the Lake Ziway, calculated based on the nutrient concentrations. A general trend which was expected was that the nutrient loads would be much higher in the rainy season than in the dry season. This is believed to be a direct consequence of increased surface run-off during rainy season.

The loads listed in Table 4 showed higher values at Ketar River and predominantly affected by urban sewage and surface runoff from agriculture than Meki River load. Hence, it can be concluded that the contribution of the Ketar River watershed to the nutrient enrichment of Lake Ziway was much higher than that of Meki River watershed. Similarly, Francisco, [20] reported that the comparison between the average inflows of Meki and Ketar Rivers clearly illustrate that Ketar River has more volume of inflow as a result of it larger catchment size; consequently Ketar River has a larger irrigational area than Meki River. These trends can be explained by the urban and agricultural surface runoff in the rainy period, which contributed significantly to the high amount of agrochemicals transported by the Ketar and Meki Rivers to the lake ecosystem.

The results of this study is supported by Chen [21], which stated that the main cause of the ecological change has been generally attributed to nutrient load from urban and agricultural human activities together with climate change. As a consequence, the increase in nutrients load is likely to have caused the recent eutrophication of the lake ecosystem owing to increased intensification of agriculture.

Table 4 External nutrient loads (kg day^{-1}) in the dry and rainy seasons of selected chemical species at the sampling sites of this study

Nutrients	Dry season			Wet season			Annual load
	K_b	M_b	Total	K_b	M_b	Total	
TP	87	21.9	109	1525	1138	2663	2772
SRP	16.7	11.9	28.6	106	96.0	202	230
TIN	222	37.6	259	3398	1268	4666	4925
TN	1346	498	1844	13975	8197	22172	24016

The annual SRP, TP, TIN and TN loads to Lake Ziway from the Ketar (K_b) and Meki (M_b) Rivers were estimated 230, 2772, 4925 and 24016 kg day^{-1}, respectively (Table 4). Nutrient loads from Ketar River accounted for 53.2 % SRP, 58.2 % TP, 73.5 %

TIN and 64 % TN loads to the lake ecosystem. From this nutrient loads Ketar River account for more than Meki River in the entire nutrient loads and these sources of nutrient loads have high contributions for eutrophication.

Determination of the trophic status of Lake Ziway

Analyses of trophic state variables

The water quality data measured (total phosphorus (TP), total nitrogen (TN), Chlorophyll-*a* (Chl-*a*) and secchi depth (SD)) for the analyses of the trophic status of Lake Ziway are shown in Figures 2 to 5.

Total phosphorus (TP): TP ranged between 108 µg L^{-1} to 340 µg L^{-1} with an average concentration of 212 µg L^{-1}. No Statistically significant differences among the six sampling sites were found (Kruskal-Wallis test, $p > 0.05$). The lowest phosphorous concentrations measured were in April (108 µg L^{-1}) during the dry season (Figure 2). Concentration of TP fluctuated significantly during the study periods while the higher values were in July (337µg L^{-1}) and August (340 µg L^{-1}) in the wet season (Figure 2).

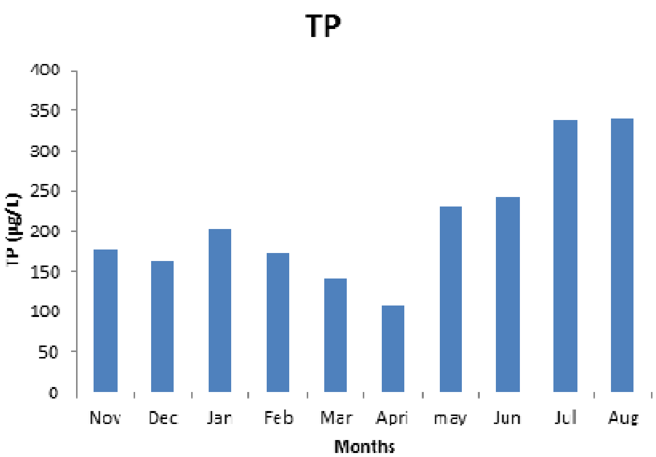

Figure 2 Monthly trends in TP concentration in Lake Ziway

The relatively high concentration of phosphorous in Lake Ziway during the rainy season could be attributed to fertilizer runoff from the surrounding agricultural fields and may be from internal phosphorous loading. Furthermore; the external nutrient load interms of the mean TP concentration due to the two feeding rivers (Meki and Ketar) was 0.25 mg L^{-1} and 0.76 mg L^{-1} in the dry and wet seasons, respectively. From this study the mean annual TP concentration due to the two rivers is 0.51 mg L^{-1}. According to Lau *et al.* [22], the mean annual TP of eutrophic lake is between $0.047 < x \leq 0.13$ mg L^{-1} and annual TP > 0.13 mg L^{-1} in hypertrophic lake. Therefore, the lake is currently eutrophic based on TP concentrations. According to Wetzel (2000), TP concentration less than 10.0 µg L^{-1} in a lake are generally considered to be oligotrophic while 100 µg L^{-1} often is used as the threshold for hyper-eutrophication. Apart from this, according to the Organization for Economic Development and Co-operation (OECD, 1982) for trophic state classification, the limit of TP for define eutrophic is 35.0 µg L^{-1}. Similarly, Ndungu *et al.* [23] reported that the TP concentration of Lake Naivasha, Kenya ranged from 27 to 410 µg L^{-1}. Thus, the value for Lake Ziway is 5.73 times greater than the prescribed limit for eutrophication. Moreover, both the internal and external TP loads showed the lake is in eutrophic state. **Total nitrogen (TN):** TN ranged from 5.54 mg L^{-1} to 7.49 mg L^{-1} with mean concentration of 6.70 mg L^{-1}. ANOVA (Kruskal-Wallis test) result showed that TN concentrations among sampling sites were significantly different ($P < 0.05$). The lowest TN concentrations measured were in May (5.54 mg L^{-1}) and the highest TN concentration was recorded in July (7.50 mg L^{-1}) (Figure 3). The relatively high concentration of TN in July (Figure 3) could be from the application of fertilizers on crop land and decomposition of organic matters washed off into the lake as important source of nutrient loading available to phytoplankton.

Limnologists and lake managers have developed a general consensus about freshwater lake responses to nutrient additions, that essentially an ambient TP concentration of greater than about 0.01 mg L^{-1} and/or TN of about 0.15 mg L^{-1} are likely to predict blue-green algal bloom problems during the growing season [18]. Similarly, chronic over enrichment leads to lake quality degradation manifested in low dissolved oxygen, fish kills, algal blooms, expanded macrophytes, likely increased sediment accumulation rates, and species shifts of both flora and fauna (US EPA, 2000 [24]). From the study, it was found that Lake Ziway, concentrations of TP and TN obtained are greater than the limit of 0.01 mg L^{-1} and 0.15 mg L^{-1}, respectively.

In addition, both the internal and external TP and TN loads showed the lake is in eutrophic state. For instance, the external TP and TN load in Lake Ziway is higher compared to some tropical eutrophic lakes like Lake Lewisville [25] and Ibirité reservoir, and TP loads for Lake Ziway is in the same range with that of eutrophic lakes, Lake Kasumigaura and Okeechobee [26].

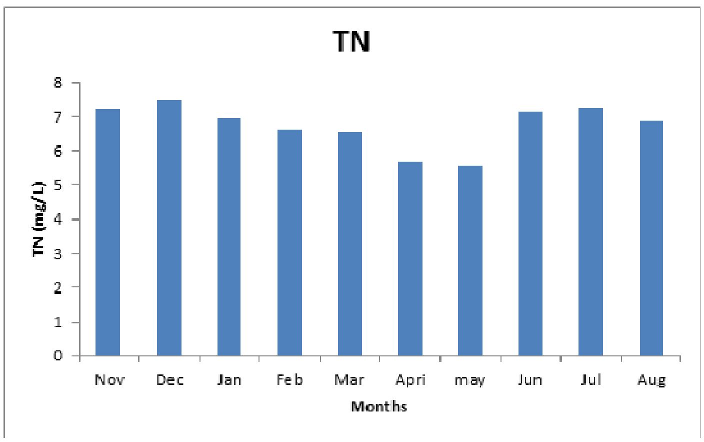

Figure 3 Monthly trends of TN concentrations in Lake Ziway

Moreover, the TN load in Lake Ziway is also in the same range with that of another eutrophic lake, Lake Donghu [26]. So as the results of these sources of nutrient loads have high contributions for eutrophication. Therefore, it can be stated that reduction in nutrient concentration will be an essential mechanism to control the process of eutrophication in the lake.

Chlorophyll-*a* (Chl-*a*): the mean concentration of chlorophyll-*a* in Lake Ziway ranged from 28 to 76 µg L^{-1} with mean values of 42 µg L^{-1}. The lowest measurements were in July (28 µg L^{-1}) and the highest chlorophyll-*a* concentration was in June (76 µg L^{-1}) (Figure 4) which is mainly due to high wind, nutrient, turbidity and rainfall in relation with plankton abundance. No significance differences among the six sampling sites were found (Kruskal-Wallis test, $p > 0.05$). Therefore, relatively higher concentrations of chlorophyll-*a* observed in the rainy season due to increase in nutrient input from the catchment. Similar results were reported by Tilahun, [5] in the same lake and Lake Hawasa. According to OECD, 1982 classification of trophic state, 8.0 µg L^{-1} of chlorophyll-*a* concentration is the threshold for eutrophication and in the present study; all in the sampling sites were found to have chlorophyll-*a* concentrations beyond the prescribed limit.

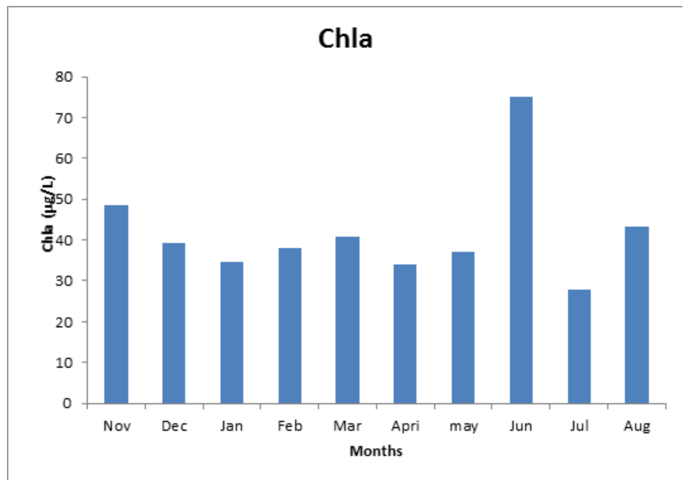

Figure 4 Monthly trends of chlorophyll-a concentrations in Lake Ziway

According to Carlson (1977) model, Table 5, the trophic state condition's using the concentrations of chlorophyll-*a* in lake Ziway have shown three scenarios: before 1966, the lake was oligotrophic but between the years 1980 to 2002, the lake was approaching to hypereutrophic state. For instance, high phytoplankton biomass of 91, 48 to 334, 150 to 212 and 82.4 µg Chl-*a* L^{-1} was reported by Belay and Wood [27], Kebede *et al.* (1994) [33], Tilahun [28] and Gebre-Mariam *et al.* [29], respectively. After 2006 up to the present the lake is in eutrophic state. For instance, moderate phytoplankton biomass of 39, 38, 56 and 42 µg Chl*a* L^{-1} was reported by Tilahun [5], Beneberu and Mengistu, [30], Tamire and

Mengistu [17] and the present study, respectively (Table 5). Previous studies based on time series of chlorophyll-*a* analysis speculated that Lake Ziway showed a progressive increase towards eutrophy [29], the result of the present study also agreed with the trend of eutrophication condition of Lake Ziway. The eutrophication of Lake Ziway might have been intensified after the rapid expansion of the flower industry, widespread fisheries, and fast population growth, industrialization and intensive use of agrochemicals in the lake watershed.

Table 5 Tends of Chla µg L-1 concentrations during the years from 1937 to 2015 in Lake Ziway

Year	Chla(µg L^{-1})	References
1937 to 1938	Clear water	[31]
1966	7	[32]
1980	91	[27]
1986	48 -334	[33]
1987 to 1988	150-212	[28]
1991	154	[34]
2002	82.4	[29]
2006	39.2	[5]
2009	26.3-57.9	[30]
2011 to 2012	56.34	[17]
2013 to 2015	28 -76	Present work

The decrease in biomass in the present study as compared to previous results can be attributed either to zooplankton grazing, other biota and/or increased non-algal turbidity. The declining trend in secchi depth (SD) reading is one of the indications which suggest the increasing trend in turbidity of the lake, which can be mainly attributed to catchment degradation and siltation. The increase in turbidity was reflected by the low SD measured during the study period as compared to previously reported values. The mean turbidity measurement in this study is 162 NTU. The low biomass but high nutrients in the lake might be due to increasing turbidity and the effect of macrophytes, as macrophytes compete for the same nutrients with algae [17]. Besides this, macrophytes might also suppress the growth of algae through the production of suppressive chemicals and/or shading [17].

As compared to other lakes, the mean concentration of chlorophyll-*a* in Lake Ziway (42 µg L^{-1}) was higher than most Ethiopian Lakes Chamo, Hawasa, Koka, Babogaya, Abaya, Kuriftu and Hayq but much lower than some East African Lakes of Chitu, Arenguade, Lakes Victoria and Naivasha in Kenya among others (Table 6).

Table 6 Comparisons of phytoplankton biomass of Lake Ziway with other lakes

Lakes	Chla(µg L^{-1})	References
Chamo	31.2	[6]
Hawasa	10.43 to 25.21	[35]
	13 to 26	[6]
Koka	16	Elizabeth and Willen (1998)
Chitu	2600	Wood and Talling (1988)
	72 to 233 (150)	[36]
Babogaya	4 to 20	[37]
Hora	29	[38]
Abaya	0 to 33	[29]
Kuriftu	17.24 to 55.6	[39]
Bishoftu	60	[37]
Arenguade	41.7 to 271	--
Hayq	12.9	[35]
Naivasha	40 to 210	[23]
Ziway	28 to 76	Present work

Secchi depth (SD): The lowest depth measurements were in May (0.16 m) and Jun (0.16 m) while the deepest measurements were in November (0.26 m) and December (0.27 m) (Figure 5). The mean SD in

Lake Ziway ranged between 0.16 to 0.27 m with a mean value of 0.20 m. The SD was lower in May to August of 2014 and 2015 which could be due to high turbidity where as in November and December when the turbidity was low, the SD was at 0.27 m, indicating the lake was clearer than it was before rainfall. ANOVA (Kruskal-Wallis Test) showed that SD values between sampling sites were not significantly different (P > 0.05).

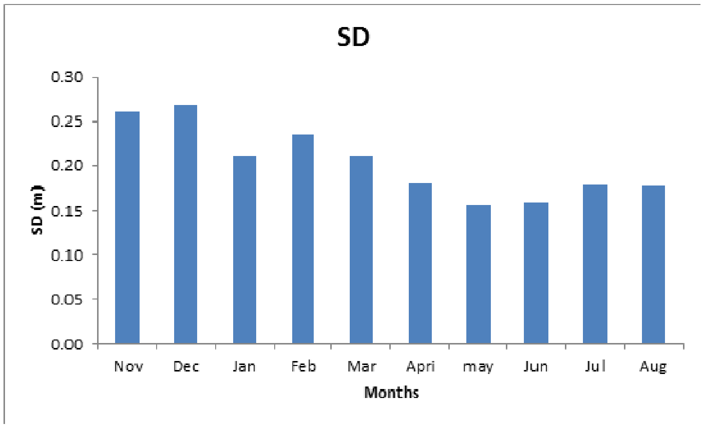

Figure 5 Monthly trends of SD transparency in Lake Ziway

According to OECD, (1982) the hypereutrophic lakes generally showed the maximum transparency values at ≤ 1.5 m and minimum transparency ≤ 0.7 m. Therefore, the present data of 0.20 m indicate Lake Ziway is a highly productive ecosystem having low euphotic zones with an indication of eutrophication.

Evaluation of the trophic status of Lake Ziway using Carlson trophic state index model

The trophic status of Lake Ziway is computed using Carlson trophic state index and Kretzer and Brezonik models which assume there is a close relationship between total phosphorous (TP), chlorophyll-*a* (chl*a),* secchi depth (SD), and total nitrogen (TN). The analytical results of the six sampling sites and Trophic State Index (TSI) are summarized in Table 7. ANOVA (Kruskal-Wallis test) showed that, the TSI-TN value was significantly different (P < 0.05) among sampling sites whereas TSI-TP, TSI-Chl-*a* and TSI-SD values were not significantly different (P > 0.05).

The mean values of TSI-TP, TSI-Chl-*a*, TSI-TN and TSI-SD were 79, 66, 81 and 83, respectively (Table 7) and are graphically presented in Figure 6. All the TSI values of TP, Chl*a*, SD and TN were above the eutrophic threshold values (Figure 6). The overall average value of Trophic State Index (TSI) of Lake Ziway is found to be 77. Generally the TSIs value below 40 corresponds to oligotrophic, between 40 and 60 - mesotrophic, from 60 to 80 - eutrophic, and above 80 - hypertrophic of the lake [40]. Moreover, these TSI values based on Carlson's trophic state classification criteria [15] clearly indicate that Lake Ziway is found in eutrophic stage during the entire study period.

Table 7 Analytical results of the six sampling sites and trophic state index in 2014 and 2015

Sites	TSI-TP	TSI-Chla	TSI-SD	TSI-TN
Fa	79.92	66.767	82.67	79.77
B	76.71	64.555	83.96	77.52
Ka	80.41	65.462	83.69	81.94
Ma	80.01	66.274	82.66	79.26
Ko	79.26	66.956	82.44	87.34
C	78.57	64.731	82.88	82.4
Mean	79	66	83	81

Likewise, when the TSI values computed in this study are compared with the OECD's standard [46], it can be seen that Lake Ziway is in eutrophic state based on the Chl*a* and TP and in hypereutrophic state based on the SD and TN.

The trophic state index of TP and TN exhibited higher trophic state probably due to the run off that comes from the Ketar and Meki Rivers watershed and the internal nutrient load has also contribute the lake eutrophication. Other studies have indicated that urban development contributes to increased TP and

TN load to nearby streams [47]. The nutrient may enter into lakes as agricultural runoff, sewage, or wastewater and also by cattle ranching; causing over enrichment of nutrients in water bodies leading to algal bloom [48]. The decaying process of dead algal biomass may also result in the depletion of dissolved oxygen in the lakes causing anoxic environment [49], which enhances nutrients release from the sediment.

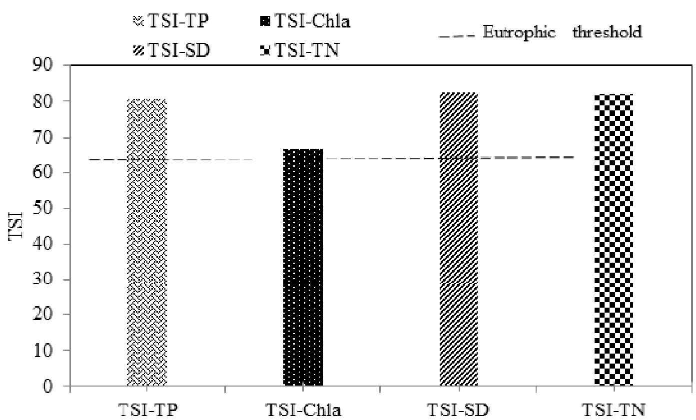

Figure 6 Trophic State Index of Ziway Lake in 2014 and 2015

This result is supported by [50] which states that human-induced changes in land- and water-use have resulted in environmental perturbations in Lake Ziway ecosystem, transforming its waters from a clear oligotrophic state, to turbid eutrophic state. Moreover, Gebre-Mariam *et al*. [23] also supported the present explanation for eutrophic status of Lake Ziway. The TSI value of Lake Ziway interms of TP, Chl*a* and SD (TP-TSI = 79; Chl*a*-TSI = 66; SD-TSI = 83) is higher than that of other Ethiopian eutrophic lakes like Lake Hayq (TP-TSI = 63; Chl*a*-TSI = 55.7) and (SD-TSI = 62; Chl*a* –TSI = 59.5) for Lake Hawasa studied by Fetahi [35] (2010). In a Similar way, Kitaka *et al.* [43]; Matthews *et al.* [51]; Ndungu *et al.* [23]; Alemayehu *et al*. [52] also reported the trophic status of Lakes Naivasha, Whatcom, Naivasha and Kaw using Carlson trophic state index model, respectively.

Total Nitrogen to Total Phosphorus (TN: TP) ratio

The ratio of total nitrogen (TN) to total phosphorous (TP) of Lake Ziway was evaluated to determine the limiting nutrient of the phytoplankton in the lake [53]. The mean TN: TP ratio of Lake Ziway is 48. Kalff [42] in his study on some tropical African lakes has shown nitrogen or phosphorus or both as growth limiting nutrients. It is well known that the TN: TP ratio in an aquatic environment is an important variable since it can indicate which of these nutrients appears to be in excess or limiting growth. The Swedish (Fisher *et al*., [54] 2005) work concluded that TN: TP ratios over the range 10 to 17 by weight show P or N (or both) limited growth, while higher ratio (>20) denoted P limitation and lower ratio (<10) shows N limitation. According to these authors Lake Ziway with mean TN: TP ratio of 48 is phosphorus limited. This result is supported by Wetzel, [55] in which phosphorus is the most probable limiting nutrient for phytoplankton growth in freshwater. Moreover, Smith, [56] reported that the TN: TP ratios have been used as a basis for estimating which nutrient limits algal growth. Galvez-Cloutier *et al*., [57] also suggested that, in freshwater where the TN: TP ratio is greater than 7, phosphorus will be the limiting nutrient, whereas for TN: TP ratios below 7, nitrogen will be the limiting nutrient for algal growth. Similarly, Tilahun, [5] reported that the TN: TP ratios were 20.8, 47.5 and 9.6 for Lakes Ziway, Hawasa and Chamo, respectively. However, Deriemaecker [41] reported that the other two Rift Valley lakes of Ethiopia, Chamo and Abaya are nitrogen limited, as the TN: TP ratios are 1.2 and 1.3, respectively. In a similar way, Kalff [42], in his study of the neighbouring Kenyan lakes has reported moderate P deficiency in the freshwater lakes of Naivasha (mean TN: TP ratio 30) and high P deficiency in Oloiden (mean TN: TP ratio 48). However, currently the lake Naivasha has been classified as eutrophic Kitaka *et al*., [43] and Ndungu *et al*., [23].

Deviations between trophic state indices

In the present study, the trophic state index determined with chlorophyll-*a* showed lower values than those determined with all trophic state index values of TN, TP, and SD, indicating that factors other than phosphorus and nitrogen limited algal growth, and the deviation of this study indicated that wind mixing and non-algal turbidity affected light attenuation in lake Ziway. Figures 7 and 8 clearly show that non-algal turbidity was the major factor for deviations between trophic state indices in Lake Ziway.

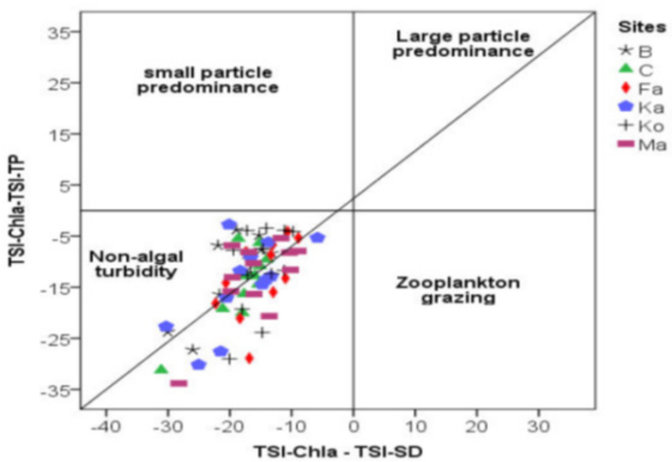

Figure 7 A plot of the deviation of TSI (Chla) from TSI (SD) versus the deviation of TSI (Chla) from TSI (TP) in 2014 and 2015

Deviations of all values were negative which lie in the non-algal turbidity (Figures 7 and 8). According to Kalff [42], deviations of the TSI-Chla from the TSI-TP emphasized phosphorus limitation on phytoplankton biomass, as expected for tropical freshwater ecosystems. However, negative values occurred coincident the TP and TN concentration were high because of catchment and urban runoff or internal mixing.

Moreover, Carlson's initial intention with the TSIs was to create equations that would produce the same TSI for a particular lake regardless of whether chlorophyll-*a*, TP, TN or SD were used to generate the index.

In theory, subtracting TSI-Chl*a* from any other TSI will be equal to zero, or nearly so, with only random variation causing deviations from zero. In reality, there are usually predictable deviations between TSI-Chl*a* and nutrient or TSI-SD that can be used to assess the degree and type of nutrient limitation in lakes [44-45].

According to Carlson and Havens [45], When TSI-Chl*a* is equal to or greater than TSI-SD, one may infer that algae dominate light attenuation.

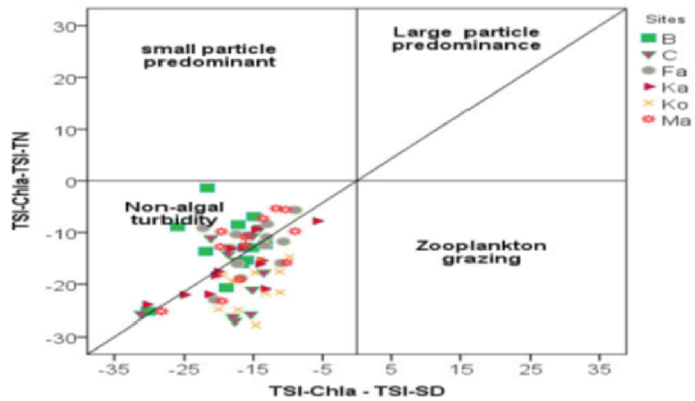

Figure 8 A plot of the deviation of TSI (Chla) from TSI (SD) versus the deviation of TSI (Chla) from TSI (TN) in 2014 and 2015

When TSI-Chl*a* is substantially lower than TSI-SD, this provides evidence that something other than algae, perhaps non-algal turbidity, is contributing to light attenuation. When TSI-Chl*a* is equal to or greater than TSI-TP, phosphorus generally is limiting to algal growth. When TSI-Chl*a* is substantially lower than TSI-TP, this indicates that there is less algal material present than expected based on TP, and that some other factors may be limiting. In the same manner, nitrogen limitation is indicated when TSI (Chl*a*) -TSI (TN) > 0 and TSI (TN) < TSI (TP). According to this the results of this study showed TSI-Chl*a* is lower than TSI-SD, providing evidences that non-algal turbidity is contributing to light attenuation. These relationships have been extensively used by most related studies (e.g., Matthews *et al.*, [51]; An and Park, [58]. For instance, Matthews *et al.* [51] employed the concept of TSI differences to assess the trophic state and nutrient limitation of Lake Whatcom (USA). An and

Park [58] used deviations of the trophic state index to illustrate that factors other than phosphorus limited algal growth, and that non-algal particles affected light attenuation in an Asian reservoir. Furthermore, Ndungu *et al.* [23] also used deviations of the trophic state index to illustrate that factors other than phosphorus limited algal growth, and that small and large particles predominates affected light attenuation in a Lake Naivasha, Kenya.

Conclusions and recommendations

In conclusion, there is a high external nutrient load from the two feeding rivers of Lake Ziway with Katar River accounting more than Meki River for the entire nutrient loads. The general trend which is also expected is that the nutrient load in the wet season was much higher than the dry season. As a consequence of high external nutrient load, eutrophication of the lake ecosystem is increasing rapidly. Therefore, the overall evaluation of the trophic status of the lake indicated that clear signals of eutrophication were observed in Lake Ziway during the study period. The results of the TN: TP ratio also indicated that phosphorus was the limiting nutrient in the lake water. Moreover, the trophic state index determined with chlorophyll-*a* showed lower value than those determined with all trophic state index values of TN, TP, and SD which indicated that wind mixing and non-algal turbidity affected light attenuation for algal growth.

In order to stop further deterioration of the lake water quality and to eventually restore the beneficial uses of the lake, management of phosphorus and nitrogen load into the lake should be given urgent priority. Measures should be taken to reduce the external nutrient loads by a multiple approaches such as catchment management to minimize soil erosion and nutrient runoff; sewage diversion; increased use of phosphorus free detergents; establishing animal fertilizer storage capacity; wetland restoration.

Acknowledgment

The authors gratefully acknowledge the support of Addis Ababa University, college of natural and computational science water thematic research group and University of Gondar for funding this research work.

Conflict of Interest

Authors declared no conflict of interest.

REFERENCE

[1] Desta, H., Lemma, B., Albert, G., Stellmacher, T. 2016. Degradation of Lake Ziway, Ethiopia: A study of the environmental perceptions of school students. Lakes and Reservoirs: Research and Management, 20, 243–255

[2] Erik, J., Mariana, M., Thomas, A., Martin, S., Torben, L., Lauridsen, K., Meryem, B., Sandra, B, Pietro, V. 2014. Climate Change Impacts On Lakes: An Integrated Ecological Perspective Based On A Multi-Faceted Approach, With Special Focus On Shallow Lakes. J. Limnol, 73, 88-111.

[3] Meshesha, T., Tsunekawa, A., Tsubo, M. 2012. Continuing land degradation: cause–effect in Ethiopia's central Rift Valley land Degradation and Development, 23**,** 130 -143.

[4] Søndergaard, M., Jeppesen, E. 2001. Retention and Internal Loading of Phosphorus in Shallow, Eutrophic Lakes. Review Article. The Scientific World, 1, 427- 442.

[5] Tilahun, G. 2006. Temporal dynamics of the species composition, abundance and size-fractionated biomass and primary production of phytoplankton in Lakes Ziway, Awasa and Chamo. Ph.D. Thesis, Addis Ababa University, Ethiopia.

[6] Tilahun, G., Gunnel, A. 2010. Seasonal variations in phytoplankton biomass and primary production in the Ethiopian Rift Valley lakes Ziway, Awasa and Chamo – The basis for fish production, *Limnologica.*, 40, 330 - 342

[7] Turdu, C., Bernard, G., Elisabeth, G. 1999.

The Ziway–Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation, Palaeogeography, Palaeoclimatology, Palaeoecology**,** 150,135–177

[8] Mepham, R., Hughes, R., Hughes, J. 1992. A directory of African Wetlands, Cambridge: IUCN, UNEP and WCMC.

[9] Legesse, D., Valett, C., Gasse, F. 2001. Precipitation-runoff modeling in the Ziway-Shala Basin, Ethiopian Rift Valley.

[10] IBC. 2005. *Site Action Plan for the Conservation and Sustainable Use of Lake Ziway Biodiversity (Rift Valley Lakes Project)*. Institute of Biodiversity, Addis Ababa, Ethiopia, 76.

[11] APHA (American Public Health Association). 1999. Standard methods for the examination of water and wastewater, 20th ed., Washington D.C

Yang, J., Skogley E., Schaff B., Kim J. 1998. A simple spectrophotometric determination of nitrate in water. Soil Sci. Soci. American J., 62**,** 1108 – 1115

[13] Talling, J., Driver, D. 1963. Some problem in estimation of chlorophyll a in phytoplankton. Proceeding Conference on primary productivity measurement, marine and fresh water U.S, Atomic energy comm., TID, 7663, 142 -150.

[14] Huai-en, L., Joseph, H., Ming, C. 2003. Nutrient Load Estimation Methods for Rivers. International Journal of Sediment Research, 18, 346-351

[15] Carlson, R. 1977. A tropical state index for lakes. Limnology and oceanography, 22, 1-10.

[16] Kretzer, R., Brezonik, P. 1981. A Carlson-type trophic state index for nitrogen in Florida lakes. *Wat. Resour. Bull*, 17,713-715.

[17] Tamire, G., Mengistou, S. 2012. Macrophytes species composition, distribution and diversity in relation to some physicochemical factors in the littoral zone of Lake Ziway, Ethiopia, Afr. J. Ecol, 51, 66 - 77.

[18] O'sullivan, P., Reynolds, C. 2004. The Lakes Handbook Volume 2 Limnology and Limnetic Ecology, Blackwell Publisher, USA.

[19] Shah, J., Pandit, A., Shah, M. 2014. Spatial and Temporal Variation of Nitrogen and phosphorus in Wular Lake Leading to Eutrophication, Ecologia, 4, 44-55.

[20] Francisco, R. MSC. 2008. Thesis, Wageningen University, Belgium

[21] Chen, Y., Fan, C., Teubner K, Dokulil M. 2003. Changes of nutrients and phytoplankton chlorophyll-a in a large shallow lake, Taihu, China: an 8-year investigation. Hydrobiologia, 506, 273 - 279.

[22] Lau, S., Lane, S. 2002. Biological and chemical factors influencing shallow lake eutrophication: a long-term study, The Science of the Total Environment**,** 288, 167-181.

[23] Ndungu, J., Augustijn, M., Hulscher, H., Kitaka, N., Mathooko, J. 2013. Lakes and Reservoirs: Research and Management*,* 18, 317 - 328.

[24] USEPA. 2000. Nutrient Criteria Technical Guidance Manual, Lakes and Reservoirs, US EPA, Washington D.C., EPA 822-B 00 -001.

[25] Gain, S., Baldys, S. 1995. Nutrient loading to Lake Lewisville, North-Central Texas, 1984-87, Water-Resources Investigations Report 95-4076

[26] Havens, K., Fukushima, T., Xie, P., Iwakuma, T., James, R., Takamura, N., Hanazato, T., Yamamoto, T. 2001. Nutrient dynamics and the eutrophication of shallow lakes Kasumigaura (Japan), Donghu (PR China), and Okeechobee. Environ. Pollul., 11, 263 – 272.

[27] Belay, A, Wood, R. 1984. Primary production of five Ethiopian Rift Valley lakes. Internat Verein Limnol., 22, 1187-1192

[28] Tilahun, G. 1988. A seasonal study on phytoplankton primary production in relation to light and nutrients in Lake Ziway, Ethiopia. MSc Thesis. Addis Ababa University, Ethiopia.

[29] Gebre-Mariam, Z. 2002. The effects of wet and dry seasons on concentrations of solutes and

phytoplankton biomass in seven Ethiopian rift-valley lakes. Limnologica, 32, 169-179.

[30] Beneberu, G, Mengistou, S. 2009. Oligotrophication Trend of Lake Ziway. SINET: Ethiop. J. Sci., 32, 141-148.

[31] Cannicci, G, Almagia, F. 1947. Notizie sulla "Facies" planctonica di alcuni laghi della Fossa Galla. Boll. Pesca Piscicolt. Idrobiol, 2, 54–77.

[32] Wood, R., Prosser, V., Baxter, R. 1978. Optical characteristics of the Ethiopian Rift valley lakes. Ethiopia. SINET-Ethiop. J. *Sc*., 1,73-85.

[33] Kebede, E., Gebre-Mariam, Z., Ahlgreen, A. 1994. Chemical Composition of Industrial Effluents and Their Effect on the Survival of Fish and Eutrophication of Lake Hawassa, Southern Ethiopia. Hydrobiologia, 288, 1 -12.

[34] Kebede, E., Willen, E. 1998. Phytoplankton in a salinity series of lakes in the Ethiopian Rift Valley. *Algolog. Studies*., 89, 63-96

[35] Fetahi, T. 2010. PhD Thesis, Vienna University, Austria.

[36] Ogato, T., Kifle, D., Lemma, B. 2015. Underwater Light climate, thermal and chemical characteristics of the tropical soda Lake Chitu, Ethiopia: Spatio-temporal variations, Limnologica, 52, 1 – 10.

[37] Major, Y. 2006. MSc, Thesis, Addis Ababa University, Ethiopia

[38] Gebre-Mariam, Z, Taylor, W. 1997. Dynamics of Phytoplankton In Relation to Physico-Chemical Factors in Lake Bishoftu, Ethiopia. J. Plankt. Res., 19, 647 - 654

[39] Dessalegn, Z. 2007. Temporal dynamics of biomass and primary production of phytoplankton in relation to some physico-chemical factors in Lake Kuriftu, Ethiopia

[40] Jarosiewicz, A., Ficek, D., Zapadka, T. 2011. Limnol. Rev, 11, 15 - 23

[41] Deriemaecker, A. 2013. MSC Thesis, Katholieke Universiteit Leuven, Belgium.

[42] Kalff, J. 1983. Phosphorus limitation in some tropical African lakes. Hydrobiologia, 100, 101-112.

[43] Kitaka, N., Harper, D., Mavuti, K. 2002. Phosphorus inputs to Lake Naivasha, Kenya, from its catchment and the trophic state of the lake. Hydrobiologia, 488, 73 – 80.

[44] Carlson, R. 1991. Expanding the Trophic State Concept to Identify Non-Nutrient Limited Lakes and Reservoirs. Enhancing the Status's lake Management Programs, 1, 59-71

[45] Carlson, R, Havens, K. 2005. Simple Graphical methods for the interpretation of relationships between trophic state variables. Lake and Reserv. *Manage*. 21, 107-118

[46] OECD (Organization for Economic Cooperation and Development). 1982. Eutrophication of waters. Monitoring, assessment and control. Environment Directorate, OECD, Paris, 154.

[47] Becht, R., Odada, E., Higgins, S. 2005. Lake Naivasha: experience and lessons learned brief. 1, 277-298

[48] Ramesh, A., Krishnaiah, S. 2014. Assessment of Trophic Status of Bellandur Lake, Bangalore, India by using USEPA Technique. Int. J. Engig. & Techno., 4, 1- 6.

[49] Prasad, D., Siddaraju, G. 2012. Carlson's Trophic State Index for the assessment of trophic status of two Lakes in Mandya district, Adv Appl Sci Res, 3, 2992 – 2996

[50] Zeray, L., Roehrig, J, Alamerew, D. 2007. Climate Change Impact on Lake Ziway Watershed Water Availability, Ethiopia, 1, 1-6.

[51] Matthews, R., Hilles, M., Pelletier., G. 2002. Determining trophic state in Lake Whatcom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation. Hydrobiologia, 468, 107-121.

[52] Alemayehu, D., Hackett, F. 2016. Water Quality and Trophic State of Kaw Lake. J. Environ Stud. 2, 1-7

[53] Smith, V. 1982. Phosphorus versus nitrogen limitation in the marine environment. Limnol Oceanogr, 27, 1101 – 1111

[54] Fisher, M, Reddy, K, Thomas, J. 2005. Internal nutrient loads from sediments in shallow, subtropical lake, lake and reservoir management, 21, 338 – 349.

[55] Wetzel, R., Likens, G. 2000. Limnological Analyses, 3rd edit., Saunders, USA

[56] Smith, S. 1984. Phosphorus versus nitrogen limitation in the marine environment. Limnology, UK.

[57] Galvez-Cloutier, R., Boillot, S., Triffaut-Bouchet, G., Bourget, A., Soumis-Dugas, G. 2010. An Evaluation of Several In-Lake Restoration Techniques to Improve the Water Quality Problem. Environ. Man, 1, 1-15.

[58] An K, Park S. 2003. Influence of seasonal monsoon on the trophic state deviation in an Asian reservoir. Water, Air and Soil Pollution. 145, 267–287.